TECHNICAL AND OPERATIONAL CONSIDERATIONS THAT SHOULD BE ADOPTED BY THE FIXED SERVICE TO FACILITATE SHARING WITH THE INTER-SATELLITE SERVICE IN THE FREQUENCY BAND 25.25-27.5 GHZ

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1. INTRODUCTION.

The National Aeronautics and Space Administration (NASA) operates a data relay satellite (DRS) network, called the Tracking and Data Relay Satellite System (TDRSS) consisting of geostationary Tracking and Data Relay Satellites (TDRS) to relay signals between low-orbiting satellites and a central earth station located at White Sands, New Mexico [1]. In concept, two or three geostationary data relay satellites are used to replace a dispersed, global network of earth stations to provide telemetry, tracking and command to low-orbiting user satellites. The DRS network currently operated by NASA consists of 5 satellites and uses frequencies in the 2 GHz and 13/15 GHz bands to communicate between the TDRS satellites and low-orbiting user satellites. Frequencies in the 14/15 GHz band are used to relay signals between the TDRS satellites and the central earth stations. Figure 1 shows a portion of the network consisting of the central earth station, geostationary TDRSs and a low-orbiting user satellite. The current TDRSS network is capable of relaying data from low-orbiting satellites at rates up to 3 MBps using the 2 GHz band and at rates up to 300 MBps using the 15 GHz band. The current network supports such user satellites as the Hubble Space Telescope and the Space Shuttle. The next generation of user satellites, which will generate data rates up to 800 MBps, will exceed the capacity of the existing TDRSS network. To meet these requirements, a new generation of TDRSs known as TDRSS H,I,J are being built for launch starting in 1999.

TDRSS H,I,J will add high capacity space-to-space relay links in the 23 GHz and the 26 GHz bands to its conventional relay links in the 2 GHz band and 13/15 GHz bands. The 23 GHz band will be used to transmit at moderate data rates from a TDRSS to a low-orbiting user satellite, and the 26 GHz band will be used by the low-orbiting user satellite to transmit at very high data rates to TDRSS. To facilitate the transmission of high data rates from the low-orbiting user satellite, TDRSS H,I,J will use a high sensitivity receiving system consisting of two independent receiving antennas with boresight gains on the order of 56 dBc and a receiving system noise temperature of 750 K. A consequence of the high-gain, low noise receiving system intrinsic to data relay satellites, is the susceptibility to interference from the emissions of other systems operating in the band.

The 25.25-27.5 GHz band (the 26 GHz band) was allocated to the inter-satellite service by the 1992 World Administrative Radio Conference (WARC-92). The use of the band by the inter-satellite service is limited to space research and Earth exploration-satellite service applications and to the transmissions of data originating from industrial and medical activities in space by Radio Regulation 881A [2]. The 25.25-27.5 GHz band is also allocated to the fixed and mobile services in the three ITU Regions. Additionally, the 27.0-27.5 GHz segment of the band is allocated to the fixed-satellite service (Earth-to-space) in Regions 2 and 3. Preliminary sharing studies that were performed prior to WARC-92 showed that limits were needed on the e.i.r.p. spectral density of point-to-point fixed service stations that radiated towards the orbital locations of data relay satellites to prevent unacceptable interference to data relay satellites. Provisional limits of 24 dBW in any 1 MHz band were applied by WARC-92 to the emissions of fixed service stations directed within 1.5 degrees of the geostationary-satellite orbit, taking into account the effect of atmospheric refraction [3]. These limits are to apply until the Radiocommunication Sector of the International Telecommunication Union (ITU-R) prepares a Recommendation on appropriate values. The development of such an ITU-R Recommendation is underway in Joint Ad Hoc Working Party 7B-9D (the JAH). This paper summarizes the work and the direction being taken by the JAH.

Section 2 of this paper summarizes the temporal characteristics of the interference to receivers onboard data relay satellites that is caused by the emissions of point-to-point radio-relay stations. Section 3 enumerates the factors being considered by Joint Ad Hoc Working Party 7B-9D, including the effect of atmospheric absorption and partial Fresnel zone blockage on point-to-point e.i.r.p. spectral density limits. Section 4 is a summary of the results of the paper and suggests studies of possible constraints on other types of fixed and mobile service systems that could be implemented in the band under the current allocation.

2. TEMPORAL CHARACTERISTICS OF INTERFERENCE TO DATA RELAY SATELLITES.

About 100,00 point-to-point radio-relay stations are expected to be installed worldwide in the 26 GHz band. They are low-cost systems that are intended to provide a range of digital radiocommunication services. The characteristics of these systems are: 1) 70% of the stations will have an e.i.r.p. spectral density less than 24 dBW/MHz, 25% between 24 and 33 dBW/MHz and 5% greater than 33 dBW/MHz; 2) transmitting antenna gain of 40 dBi; 3) channelization plan in accordance with Recommendation ITU-R F.748-1 [4], with bandwidths ranging from 112 MHz to 3.5 MHz and 2.5 MHz (there is a possibility that the bandwidths will be reduced to 1.75 MHz and 1.25 MHz in the future); 4) elevation angles are typically in the range from 0 degrees to 5 degrees; 5) path lengths are typically in the 2 km to 5 km range; and, 6) large rain fade margins are needed to ensure an availability of 99.999% [5].

Simulations were performed to evaluate the amount of interference that a global deployment of these point-to-point radio-relay systems might cause to data relay satellite networks. The simulations showed that the aggregate interference to a data relay satellite from the emissions of a global deployment of point-to-point radio-relay systems is not likely to exceed an acceptable level of -178 dBW/kHz (-148 dBW/MHz) for more than 0.1% of the time as given in Recommendation ITU-R SA.1155 [6]. The simulations showed that interference in excess of acceptable levels would, however, be experienced for near-boresight-to-boresight coupling between the fixed service station transmitting antenna and the DRS receiving antenna [5].

The temporal characteristics of the interference to a data relay satellite have been determined for two scenarios and compared to the protection criteria given in Recommendation ITU-R SA.1155. In the first scenario, it was assumed that a DRS is tracking an Earth observing satellite which is in a 797 km orbit inclined 98.6 degrees to the equatorial plane. In the second scenario, the DRS is tracking a spacecraft, such as the international space station, in a 350 km orbit inclined 51.7 degrees to the equatorial plane. In both scenarios, it was assumed that a fixed service station located at 45 degrees N. latitude and appearing on the limb of the Earth as viewed from the DRS, was radiating at an e.i.r.p. spectral density of 27 dBW/MHz towards the DRS. No account was taken of such mitigating factors as atmospheric absorption and Fresnel zone blockage. For both scenarios it was assumed that the DRS used a 56 dBc receiving antenna to track the low-orbiting satellite.

The boresight interference *I* received by the DRS may be determined from

$$I = \frac{\rho_T A_{iso} G_o}{4\pi R_s^2} \qquad \text{Watts/MHz} \tag{1}$$

where: ρ_T is the e.i.r.p. spectral density of the fixed service station in the direction of the DRS (W/MHz), A_{iso} is the area of an isotropic antenna ($\lambda^2/(4\pi)$, λ is the wavelength in meters), G_o is the boresight gain of the DRS receiving antenna (numeric corresponding to 56 dBc), and R_s is the slant range from the fixed service station to the DRS (approximately 41,700,000 meters).

Using equation (1), it will be found that the protection criteria of -148 dBW/MHz will be exceeded by 20 dB for boresight coupling when the e.i.r.p. spectral density is 27 dBW/MHz. Thus, the interference criterion will be exceeded when the fixed service station appears within the 20 dB beamwidth of the DRS receiving antenna. In the off-axis region where the antenna gain is down by no more than 20 dB, the off-axis gain of the DRS receiving antenna, when expressed in dB, may be approximated by the reference radiation pattern given in Recommendation ITU-R S.672-2 [7] for satellite antennas with circularly symmetric patterns

$$G(\phi) = G_O - 12\left(\frac{\varphi}{\varphi_3}\right)^2 \text{ dBc} \tag{2}$$

$$\varphi_3 = \sqrt{\frac{27{,}000}{10^{0.1\bullet G_o}}} \quad \text{degrees} \tag{3}$$

where $G(\varphi)$ is the off-axis gain (dBc), G_o is the boresight gain (dBc), φ is the off-axis angle (degrees), and φ_3 is the 3 dB beamwidth of the antenna (degrees).

A simulation program was used to evaluate the interference characteristics for the two scenarios. In both cases the simulations covered a period of 30 days in 2 second increments. The results of the simulations for the Earth observing type orbit are given in Figures 2a and 2b, and the results for the international space station type orbit are given in Figures 3a and 3b. Figure 2a shows the approximate elapsed time between the beginning of consecutive interference events. An interference event is defined as the time during which the level of interference received by the DRS exceeds the level given in Recommendation ITU-R SA.1155. Figure 2a shows the distribution for a total of 39 interference events that occurred during the simulated 30 day period. The smallest elapsed time between seven consecutive interference events was on the order of 5 hours, whereas, the maximum elapsed time between consecutive interference events was found to be up to about 52 hours.

A time series of the interference events for the Earth observing type orbit is shown in Figure 2b. As the figure shows, a number of the interference events consisted of levels of interference corresponding to boresight-to-boresight coupling. The duration of an interference event could be as short as a few seconds or as long as 80 seconds. The aggregate duration of the interference to the DRS from the emissions of a single station was 2168 seconds. This amounted to 0.084% of the time, or just slightly less than the 0.1% criterion in Recommendation ITU-R SA.1155.

Figure 3a shows the time interval between consecutive interference events when tracking a satellite in an international space station type orbit. For this type orbit, there were a total of 88 interference events during a simulated period of 30 days. The shortest time between interference events was about 1.5 hours. This occurred for four of the interference events. The elapsed time between nine of the interference events was on the order of 18 hours.

Figure 3b shows a time series of the interference events for the international space station type orbit. The figure shows that there were a number of boresight-to-boresight interference events. It also shows that the duration of an interference event could be as short as a few seconds or as long as 170 seconds. The aggregate duration of the interference to the DRS from the emissions of a single station was 7064 seconds which amounts to 0.273% of the time, or almost three times the 0.1% criterion in Recommendation ITU-R SA.1155.

3. TECHNICAL AND OPERATIONAL FACTORS TO REDUCE INTERFERENCE TO DRS.

There are several technical and operational factors being considered by Joint Ad Hoc Working Party 7B-9D that may be used by the fixed service to reduce the degree of interference to DRS operations from the emissions of point-to-point radio-relay stations in the 25.25-27.5 GHz band [8]

- Limit the e.i.r.p. spectral density of the emissions towards specific DRS orbital locations to 24 dBW/MHz.
- Use automatic transmit-power control (ATPC) such that the e.i.r.p. spectral density during non-faded conditions is 10 dB or more below the maximum e.i.r.p. spectral density of the fixed service station.
- Take into account atmospheric absorption on a site-by-site basis so as to ensure that unnecessary restrictions are not being placed on fixed service operations.
- Take into account Fresnel zone blockage on a site-by-site basis, again, to ensure that unnecessary restrictions are not being placed on fixed service operations.

Each of these factors is discussed below.

3.1 LIMIT FIXED SERVICE STATION EMISSIONS TOWARDS SPECIFIC DRS ORBITAL LOCATIONS.

As presented in Section 2, the interference to DRS receivers is primarily experienced when there is boresight-to-boresight, or near boresight-to-boresight coupling between the DRS receiving antenna and the fixed service station transmitting antenna. One means to control this type of interference is to place a limit on the e.i.r.p. spectral density radiated towards the geostationary-satellite orbit as a whole. This approach is used in bands that are shared between the fixed service and the fixed-satellite service, and is quite reasonable for these bands since the use of the geostationary-satellite orbit is quite intense. Orbital spacing between geostationary satellites in the fixed-satellite service can be quite small, less than 2 degrees, and the orbital locations of satellites in various FSS networks can be relatively dynamic in response to new service requirements and the need to accommodate new networks. In contrast, there are a limited number of DRS networks planned. For this reason, Joint Ad Hoc Working Party 7B-9D has tentatively agreed to recommend that, where practicable, the e.i.r.p. spectral density of fixed service stations emissions towards specific DRS orbital locations [9] be limited to 24 dBW/MHz. (A higher limit of 33 dBW/MHz will likely apply to the remaining locations on the geostationary-satellite orbit.) This prevents an unnecessary burden being put on the installation of point-to-point radio-relay stations in the 25.25-27.5 GHz band.

3.2 USE AUTOMATIC TRANSMIT-POWER CONTROL

Automatic transmit-power control is a very effective means to reduce the e.i.r.p. spectral density for large percentages of time. ATPC is a technology that was developed to reduce interference to radio-relay stations from the emissions of other radio-relay stations, and to thereby improve intraservice sharing and promote efficient use of the spectrum. The idea is the transmit at relatively low power during the large percentages of the time when the line-of-sight link is performing nominally. When the link becomes impaired as a result of multipath fading (predominates at frequencies below about 15 GHz) or absorption and scattering due to precipitation (predominates at frequencies above about 15 GHz), the transmitter power is automatically increased to mitigate against the fade. The difference between the nominal output power during non-faded conditions and the maximum output power during fading is typically 10 dB to 15 dB. Joint Ad Hoc Working Party 7B-9D is recommending that, where practicable, fixed service stations using ATPC not increase the e.i.r.p. spectral density of their emissions towards the orbital locations of DRS satellites to more than 33 dBW/MHz.

3.3 ATMOSPHERIC ABSORPTION.

Atmospheric absorption along Earth-to-space paths can be substantial in the 26 GHz band, particularly at low elevation angles. Joint Ad Hoc Working Party 7B-9D has agreed that atmospheric absorption may be taken into account on a site-by-site basis when determining the e.i.r.p. spectral density of emissions towards the protected DRS orbital locations. The amount of atmospheric absorption at any given frequency is a function of the water vapor density, the height of the transmitting antenna above sea level, and the elevation angle to the DRS. Water vapor density at sea level is, to a first-order analysis, a function of geographic location and time of year. A conservative approach would be appropriate for the purpose of determining the effect of atmospheric absorption on the acceptable e.i.r.p. spectral density. Specifically, it is proposed to use the monthly mean value for either February or August, whichever month yields the lowest water vapor density for the particular geographic location. The global data given in Recommendation ITU-R PN.836 [10] should be used.

Recommendation ITU-R PN.676-1 [11] provides a detailed procedure for calculating atmospheric absorption. The results of a typical set of calculations for the 26 GHz band are shown in Figure 4 for a fixed service station located at sea level and at 500 meters above sea level near 45 degrees N. latitude in Europe. At this location, the mean water vapor density is between 2 gm/m^3 and 5 gm/m^3 during February [10]. For stations at sea level, atmospheric absorption can amount to between 8.5 dB and almost 16 dB at zero elevation angle, decreasing to about 1 dB at elevation angles of 10 degrees. For stations located at 500 meters above sea level, atmospheric absorption is reduced to between 5 dB and 8 dB at zero elevation angle, and to about 1 dB at 10 degree elevation angles.

3.4 FRESNEL ZONE BLOCKAGE.

Fresnel zone blockage is another factor that, under certain circumstances will reduce the e.i.r.p. spectral density of the emissions from a fixed service station towards DRS orbital locations. The reason Fresnel blockage may be an effective means to reduce the interference to DRSs is based on the way that point-to-point radio-relay systems are expected to be used in the 26 GHz band. As explained in Section 2, these systems are expected to mainly provide digital links over paths that are on the order of 2 km to 5 km. In urban areas, the transmitting and receiving antennas are expected to be mounted on the sides of tall buildings rather than at the top of tall towers. Thus, for these sites, there is the possibility that the roof of the building on which the receiving antenna is mounted will act as a diffracting obstacle in the path between the transmitting antenna and the DRS. A first-order analysis will provide an insight into the significance of Fresnel zone blockage as a factor leading to the relaxation of e.i.r.p. spectral density limits on the emissions of point-to-point fixed service stations towards the orbital locations of DRSs.

This simplified analysis is based on Section 4.1 of Annex 1 to Recommendation ITU-R PN.526-3 [12]. The obstacle is modeled as a single knife edge as shown in Figure 5. The transmitting station is located at P_1 and the receiving DRS is located at P_2. The distance from the transmitting station to the diffracting obstacle is d_1. The distance to the DRS is so great that it is not a factor in the calculation of the diffracted field. The height of the obstacle above the direct path is denoted by h. The angle of diffraction, denoted by θ, is in radians and has the same sign as h. (The angle θ is assumed to be less than 0.2 radians, or 12 degrees.)

A dimensionless parameter ν is introduced that permits, with the aid of Figure 6, the calculation of the resultant field based on the geometrical factors listed above and the wavelength λ of the operating frequency.

$$\upsilon = \theta\sqrt{\frac{2d_1}{\lambda}} \tag{4}$$

An example will provide some bounds on the amount of attenuation of the emissions that may be expected from sites where Fresnel zone blockage is a factor.

Assume that the receiving antenna is mounted on the top of a building that is 4 km from the transmitting antenna. The top of the building approximates a single knife-edge obstacle. The transmitting antenna has a gain of 40 dB, a 3 dB beamwidth of 1.10 degrees and an unobstructed path to the receiving antenna. It is further assumed that the beam of the transmitting antenna lies equally above and below the top of the building. For an operating frequency of 26 GHz, equation (4) evaluates to

$$\nu = 833 \bullet \theta \tag{5}$$

When $\theta = 0$, the parameter ν is 0 for an off-axis angle of 0. From Figure 6, this leads to a diffraction loss of 6 dB for a DRS receiving antenna that is located in back of the obstacle on a straight line that connects the three points: the transmitting antenna, the top of the obstacle and the receiving antenna. As the off-axis angle is increased to 0.1 degrees (corresponds to an off-axis loss of only 1.5 dB from the transmitting antenna boresight gain), the parameter ν decreases to about -1.5. From Figure 6, the diffraction loss is now 0 dB. As can be seen from these simple calculations, the difference between a diffraction loss of 6 dB and no diffraction loss is only 0.1 degrees. Consequently, the viability of Fresnel zone blockage as a factor to use to relax the e.i.r.p. spectral density limits on fixed service stations towards a DRS is questionable.

4. SUMMARY AND CONCLUSIONS.

Joint Ad Hoc Working Party 7B-9D is preparing a recommendation to limit the interference to data relay satellites from the emissions of point-to-point radio-relay stations operating in the 25.25-27.5 GHz band. To meet the DRS protection criteria [6], it will be necessary for fixed service stations to limit the e.i.r.p. spectral density of their emissions towards specific DRS locations to 24 dBW/MHz and their emissions towards other locations on the geostationary-satellite orbit to 33 dBW/MHz. If automatic transmit-power control is used, the maximum e.i.r.p. spectral density during faded conditions in the direction of specific DRS locations should not exceed 33 dBW/MHz. Atmospheric absorption may be factored into determining the e.i.r.p. spectral density limits for individual fixed service sites. The mean water vapor content for the driest month (either February or August) and the height of the fixed service station transmitting antenna above sea level are to be used in the calculation. Fresnel zone blockage may be taken into account. However, a sensitivity analysis is needed to verify that minor changes in the transmitting antenna pointing angle, such as 0.1 degrees, does not have a major effect on the level of interference.

The studies summarized here are only concerned with interference to DRS networks from the emissions of point-to-point radio-relay systems. There are other types of fixed service systems, and mobile service systems as well, that could be introduced into the 26 GHz band. Further study is required to ensure that the parameters recommended for point-to-point fixed service systems will provide the required protection to DRS networks when applied to other types of fixed service and mobile service systems.

REFERENCES

[1] A.B. Comberiate, D.H. Lewis, J. Deskevich, D.J. Zillig, K.H. Chambers and W.D. Horne, “Global, High Data Rate Ka-Band Satellite Communications, NASA’s Tracking and Data Relay Satellite System,” presented at the First Ka Band Utilization Conference, Rome, Italy, September 1995.

[2] Radio Regulations, International Telecommunication Union, Geneva, Switzerland, Edition of 1990, Revised 1994.

[3] Radio Regulation 2504A, Radio Regulations, International Telecommunication Union, Geneva, Switzerland, Edition of 1990, Revised 1994.

[4] “Radio Frequency Channel Arrangements for Radio-Relay Systems Operating in the 25, 26 and 28 GHz Bands,” Recommendation ITU-R F.748-1, International Telecommunication Union, Geneva, Switzerland, dated 1992.

[5] “Sharing of the Frequency Band 25.25-27.5 GHz Between the Inter-Satellite and Fixed Services,” United States of America, Document 7B/22 (9D/31), dated 14 March 1996.

[6] “Protection Criteria Related to the Operation of Data Relay Satellite Systems,” Recommendation ITU-R SA.1155, International Telecommunication Union, Geneva, Switzerland, dated 1995.

[7] “Satellite Antenna Radiation Pattern for Use as a Design Objective in the Fixed-Satellite Service Employing Geostationary Satellites,” Recommendation ITU-R S.672-2, International Telecommunication Union, Geneva, Switzerland, dated 1993.

[8] “Maximum Equivalent Isotropically Radiated Power of Transmitting Stations in the Fixed Service Operating in the Frequency Band 25.25-27.5 GHz Shared with the Inter-Satellite Service,” Preliminary Draft New Recommendation, Document 7B/TEMP/13-E (9D/TEMP/15-E), International Telecommunication Union, Geneva, Switzerland, dated 25 March 1996.

[9] “Orbital Locations of Data Relay Satellites to be Protected from the Emissions of Fixed Service Systems Operating in the Band 25.25-27.5 GHz,” Preliminary Draft New Recommendation, Document 7B/TEMP/5-E, International Telecommunication Union, Geneva, Switzerland, dated 13 March 1996.

[10] “Surface Water Vapor Density,” Recommendation ITU-R PN.836, International Telecommunication Union, Geneva, Switzerland, dated 1992.

[11] "Attenuation by Atmospheric Gases in the Frequency Range 1-350 GHz," Recommendation ITU-R PN.676-1, International Telecommunication Union, Geneva, Switzerland, dated 1992.
[12] "Propagation by Diffraction," Recommendation ITU-R PN.526-3, International Telecommunication Union, Geneva, Switzerland, dated 1994.

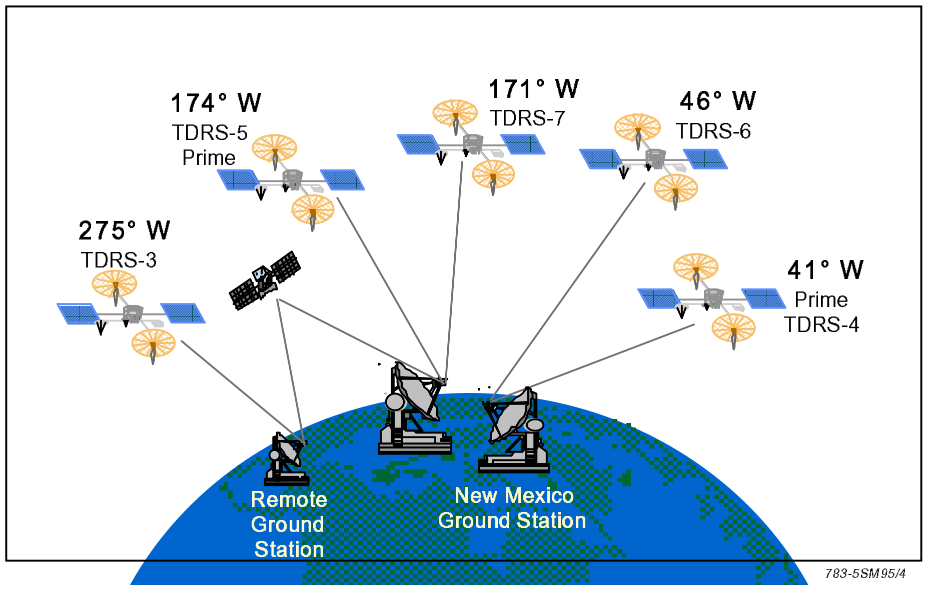

Figure 1 - Typical deployment of NASA's Tracking and Data Relay Satellite System (TDRSS).

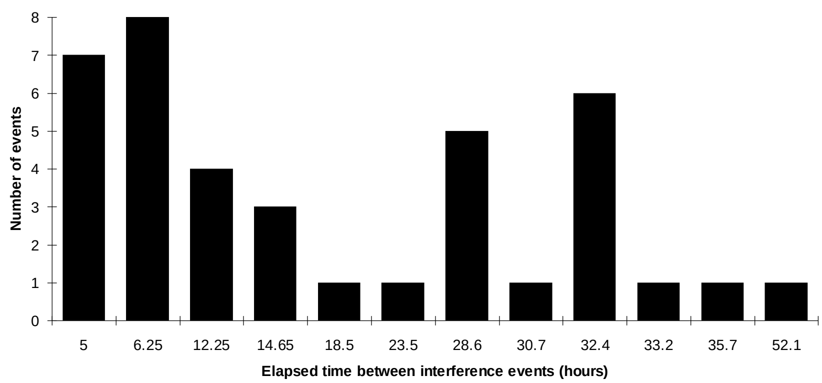

Figure 2a - Elapsed time between consecutive interference events when tracking a satellite in an Earth observing type orbit.

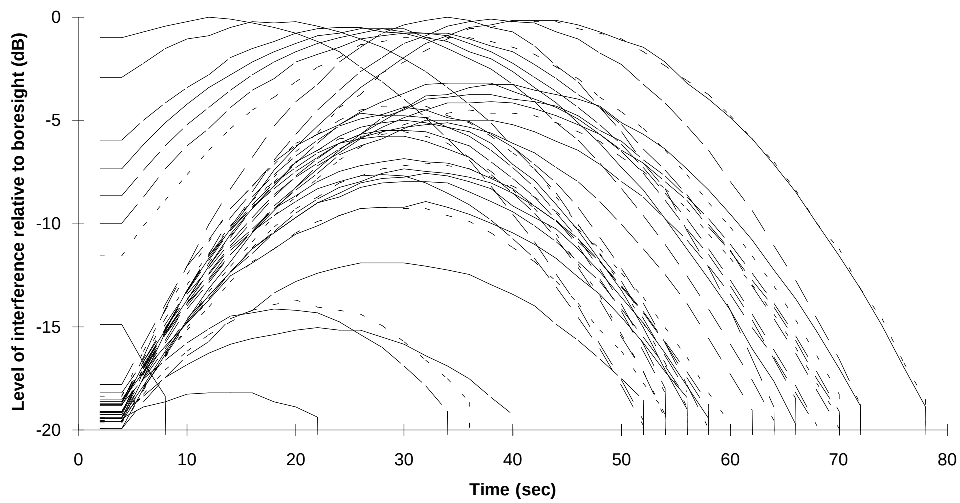

Figure 2b - Time series of interference events when tracking a satellite in an Earth observing type orbit.

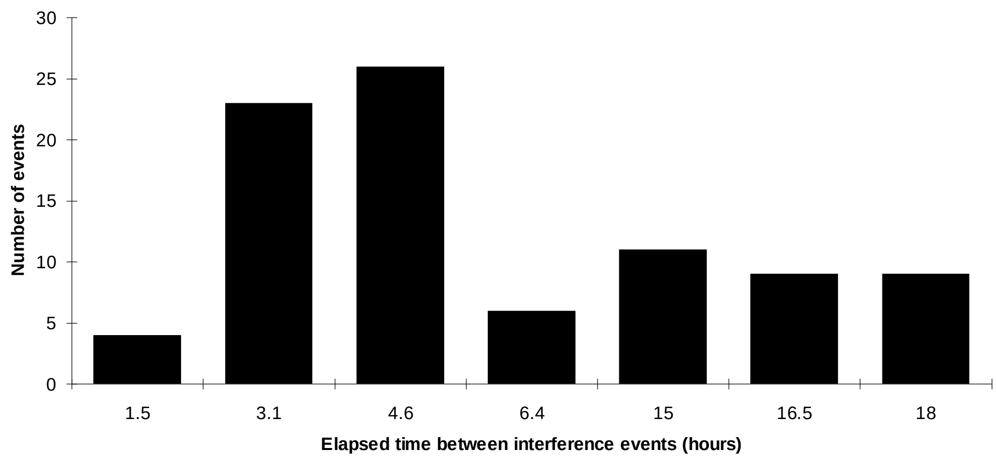

Figure 3a - Elapsed time between consecutive interference events when tracking a satellite in an international space station type orbit.

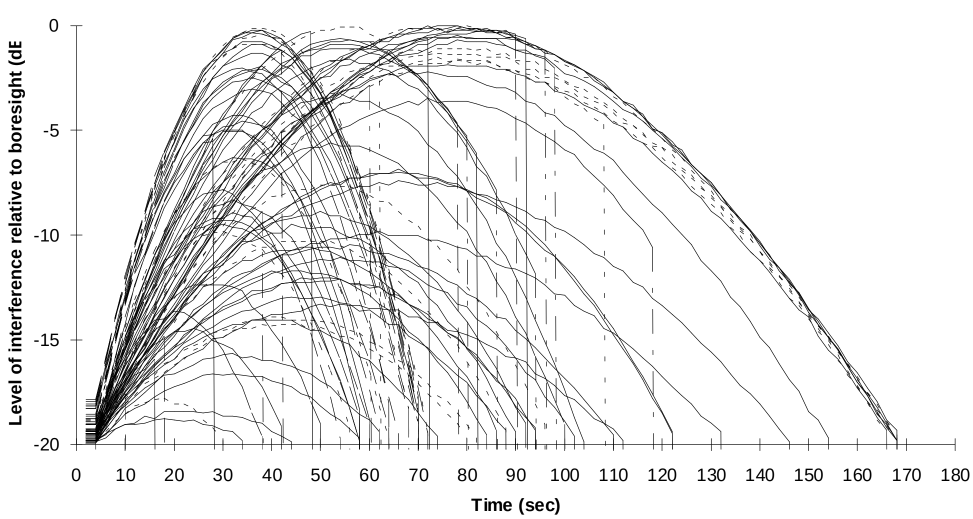

Figure 3b - Time series of interference events when tracking a satellite in an international space station type orbit.

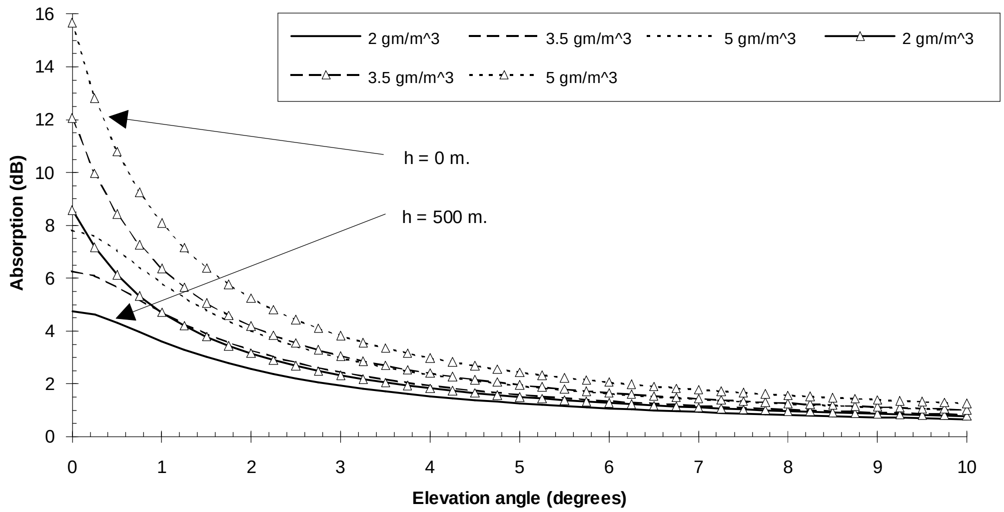

Figure 4 - Atmospheric absorption as a function of elevation angle for a station at sea level and at a height of 500 meters above sea level.

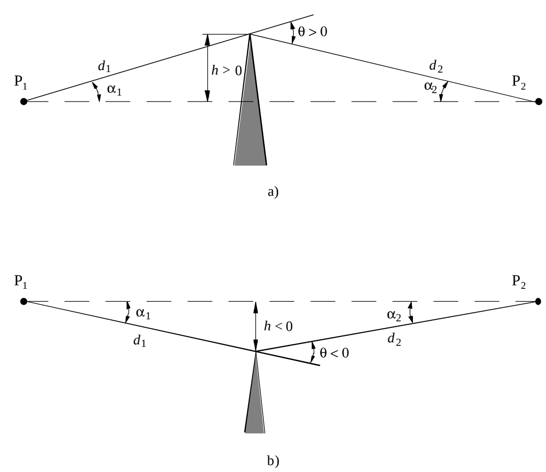

Figure 5 - Geometry for the analysis of knife-edge diffraction [12].

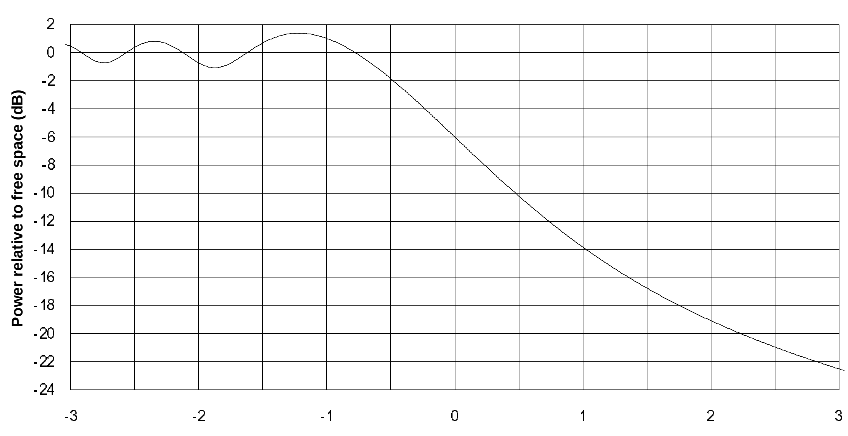

Figure 6 - Knife-edge diffraction loss [12].